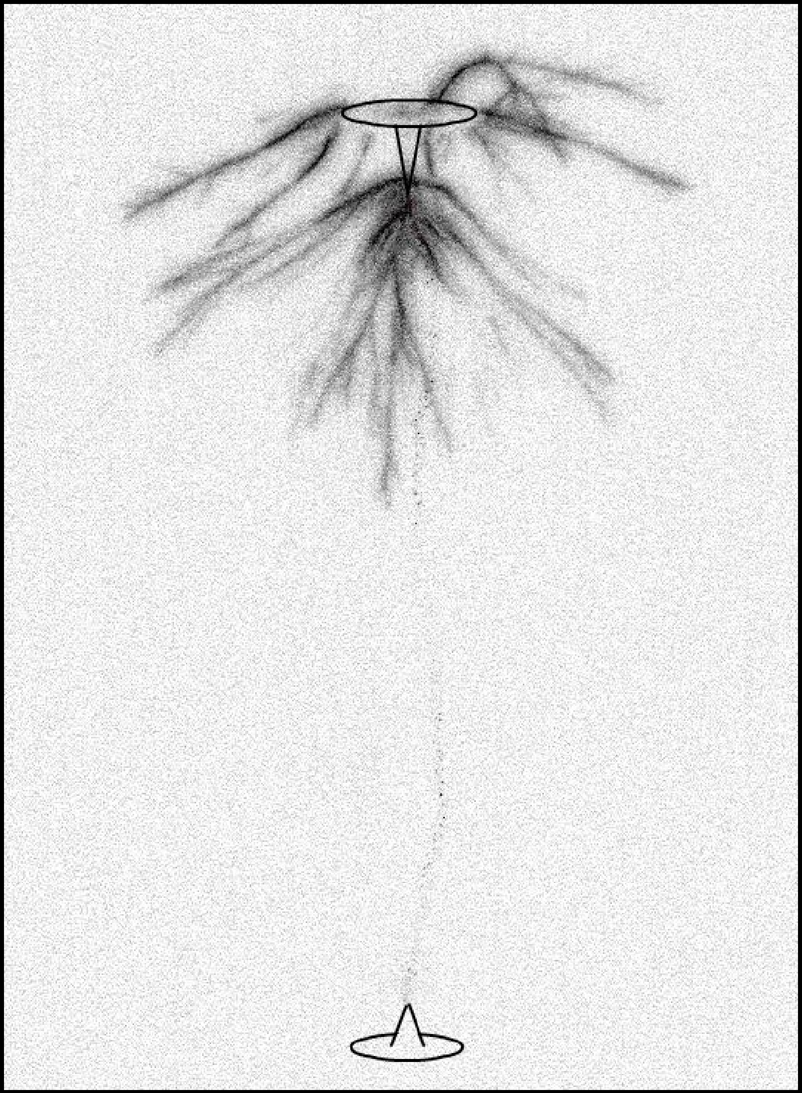
Motion of electrons in a gas

Negative discharge
With U=-1 MeV



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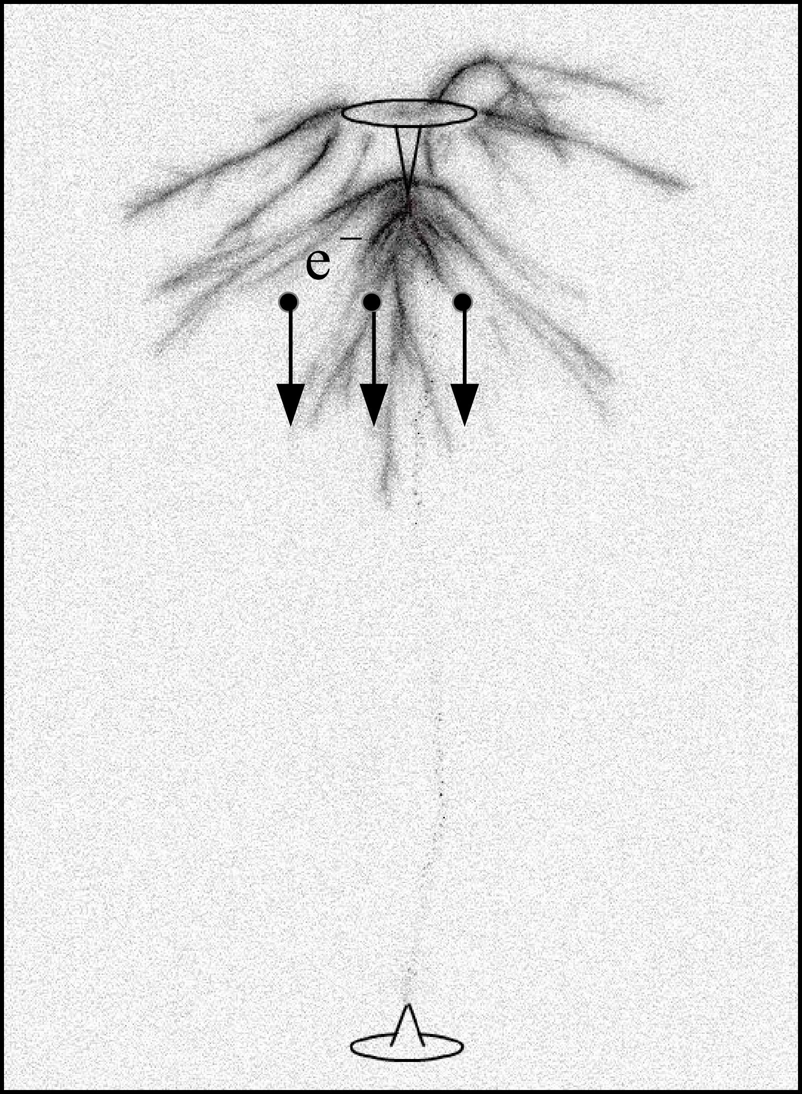
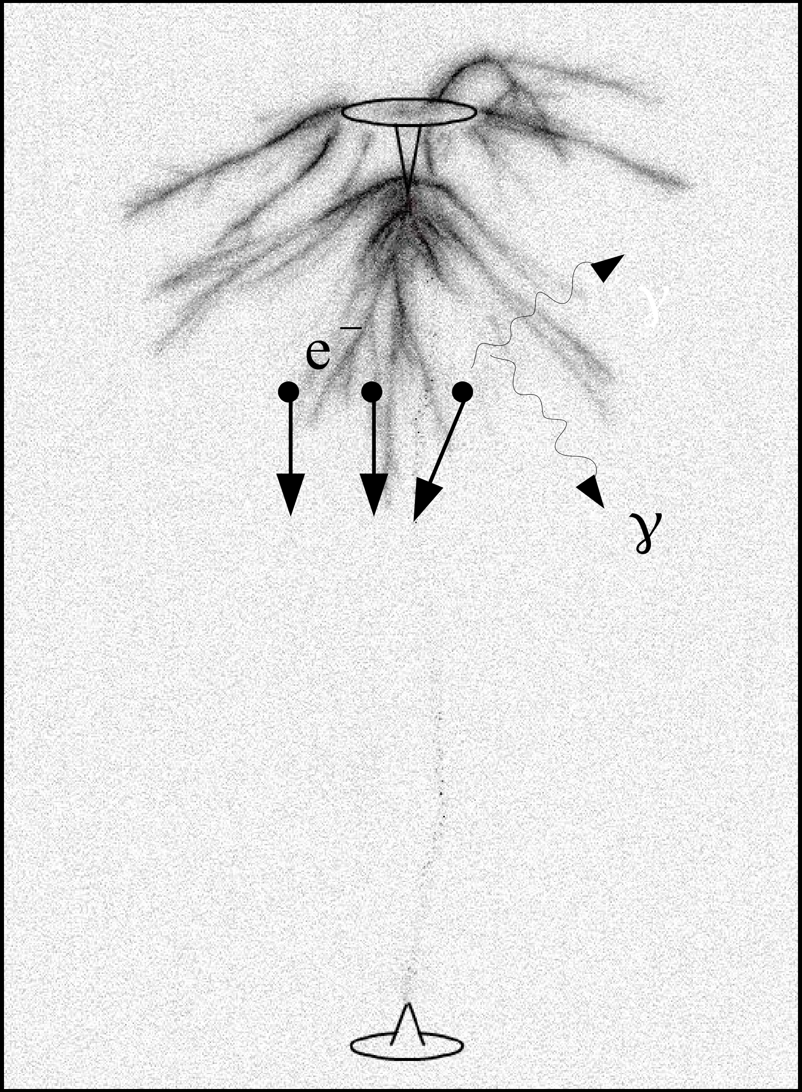
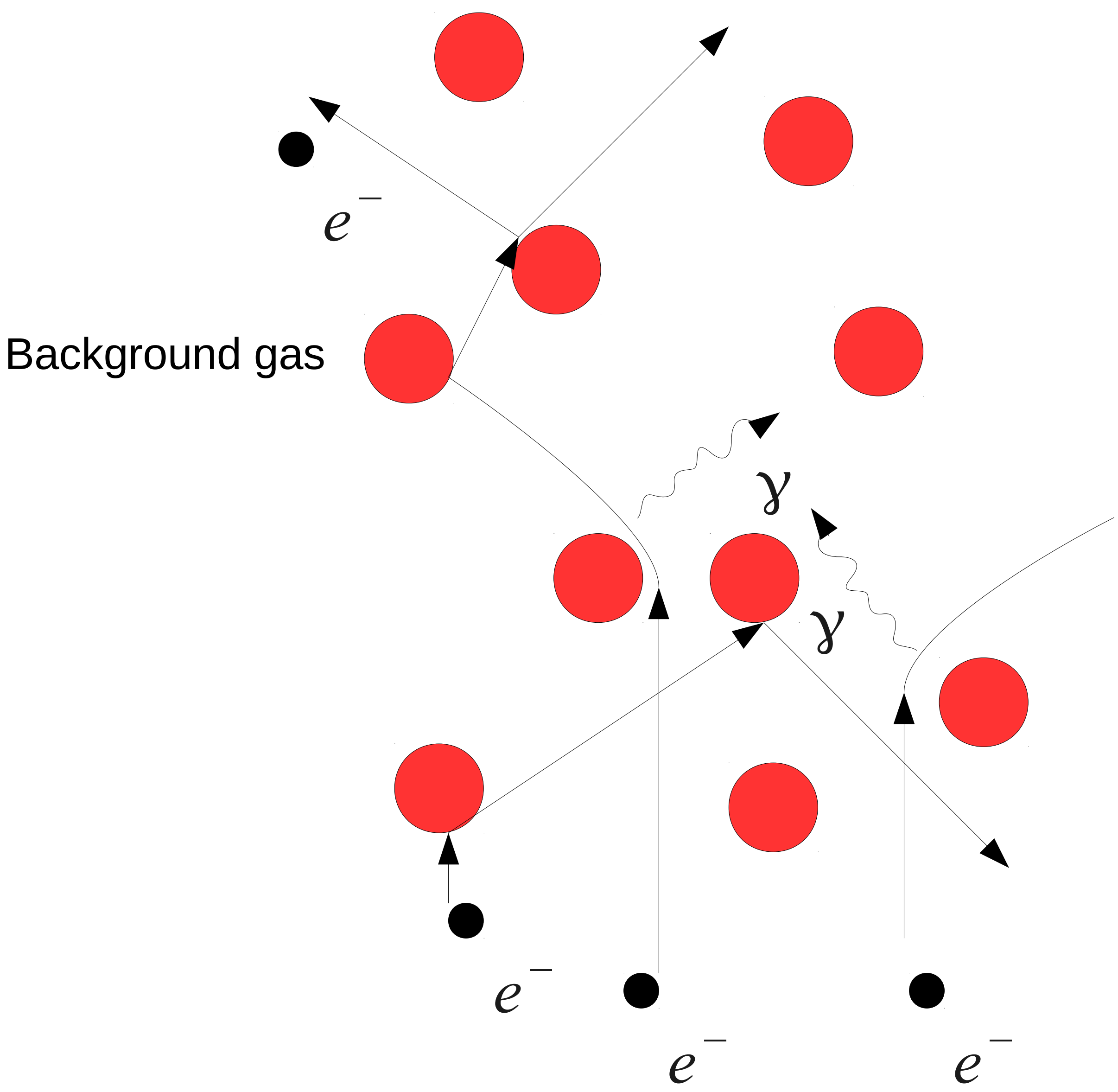


Motion of electrons in a gas

Negative discharge
With U=-1 MeV

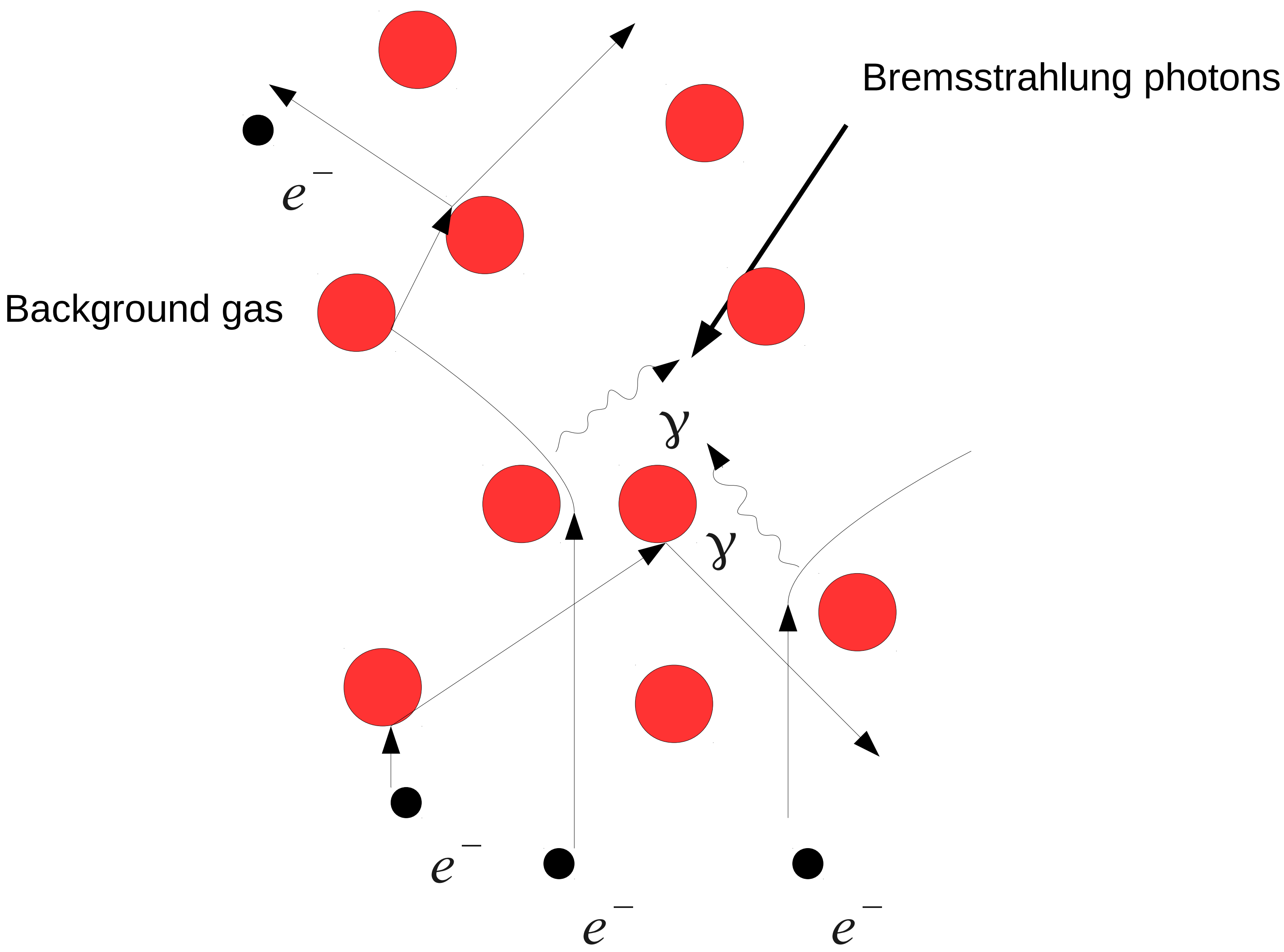

e^-
γ
γ

Motion of electrons in a gas



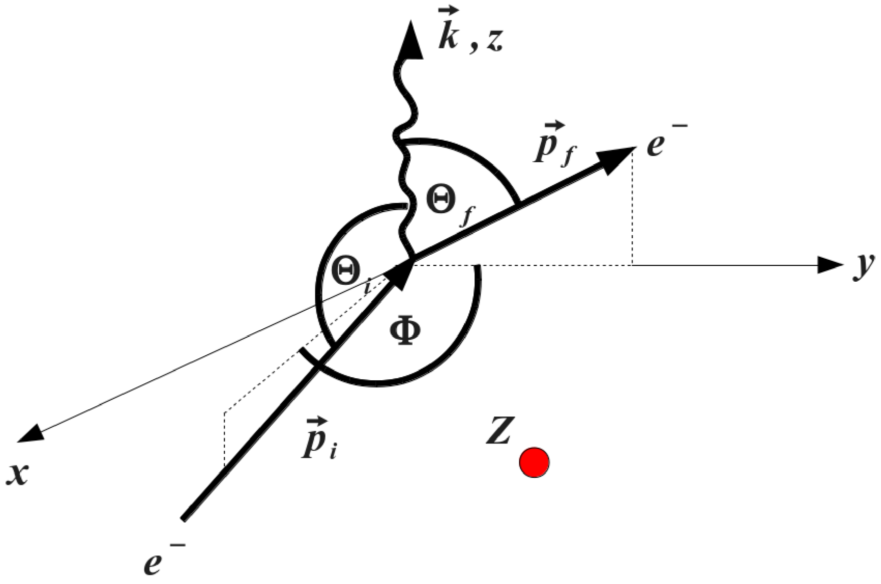
Background gas
e^-
γ
γ
e^-
e^-
e^-

Motion of electrons in a gas


Bremsstrahlung photons
Background gas
e^-
γ
γ
e^-
e^-
e^-

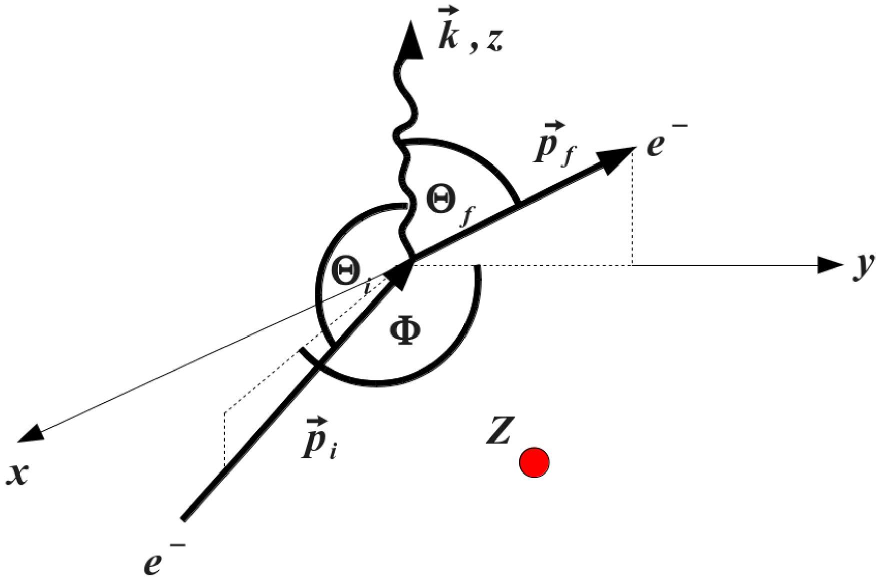
Collisions with background gas: => Creation of Bremsstrahlumg photons

Bremsstrahlung


$\vec{k}$, z
$\vec{p}_f$
e^-
Θ_f
Θ_i
y
Φ
x
$\vec{p}_i$
Z
e^-

Physical quantities:
i) kinetic energy of incident electron
ii) energy of created photon
iii) three angles

Bremsstrahlung



Physical quantities:
i) kinetic energy of incident electron
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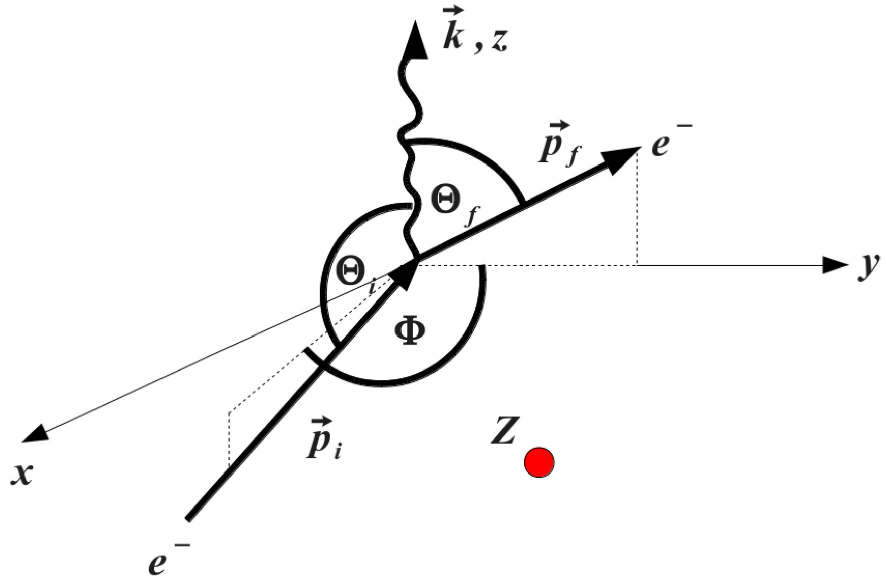
Bremsstrahlung process described by:

$$\Rightarrow \frac{d^4\sigma}{d\omega\, d\Omega_i\, d\Omega_f\, d\Phi}\left(E_{kin,i}, \omega, \Theta_i, \Theta_f, \Phi\right)$$

$\sim$ Probability of a certain process for $E_{kin,i} > 1\,\mathrm{keV}$ and $Z = 7,8,18$

[H. A. Bethe and W. Heitler, 1934, Proc. Phys. Soc. London, vol. 146, pp. 83-112]

Bremsstrahlung



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Problem: Correlation between energy of photon and its direction

=> Integrate out Φ and Θ_f

[Koehn, C., and U. Ebert (2013), Angular distribution of Bremsstrahlung photons and of positrons for calculations of terrestrial gamma-ray flashes and positron beams, Atmos. Res., http://dx.doi.org/10.1016/j.atmosres.2013.03.012]

Modelling

- Start with monoenergetic beams with E=100 keV, 200 keV,..., 1MeV (500 000 electrons)

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  - Attachment
  - Excitation
  - Elastic scattering
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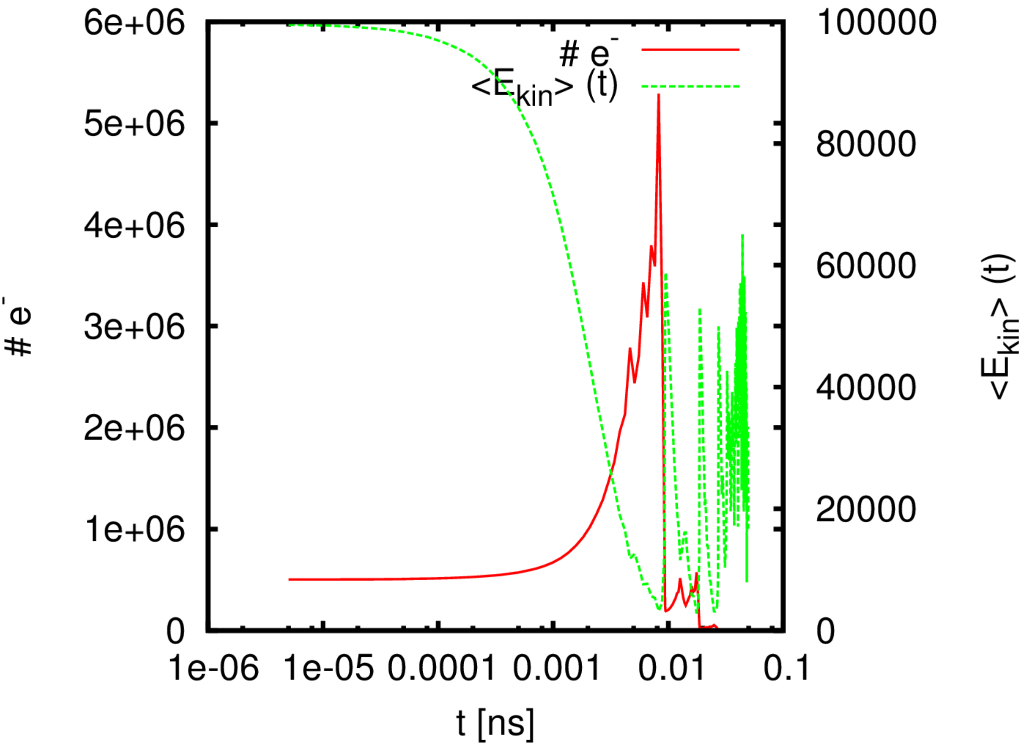
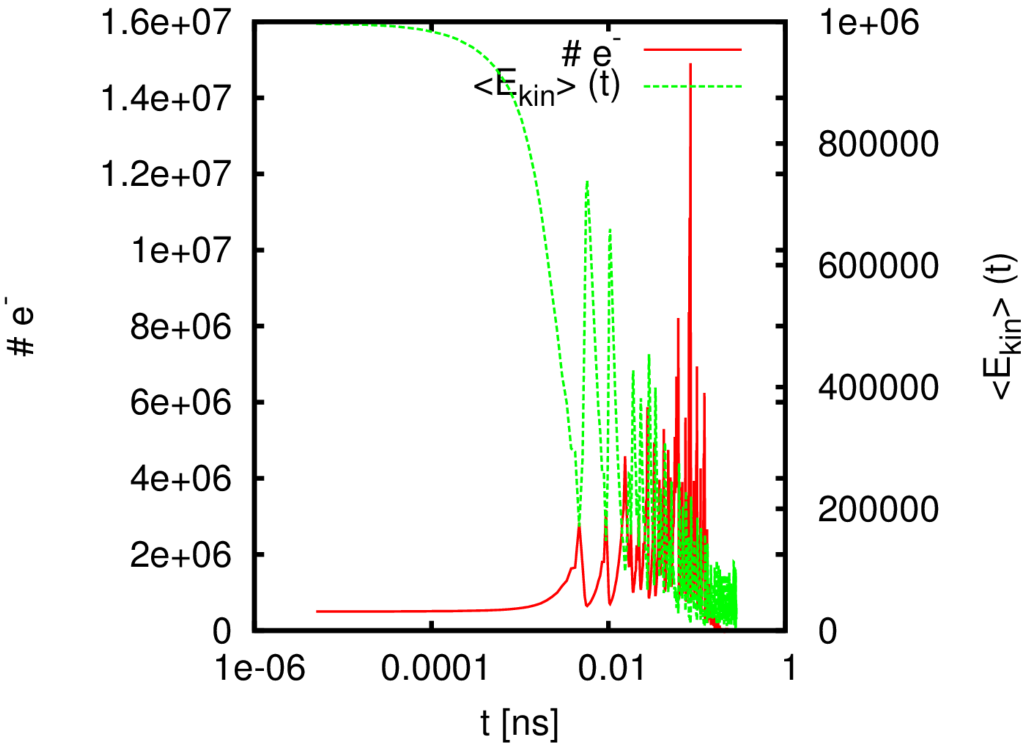
  - Excitation
  - Elastic scattering
  - Bremsstrahlung
- Photon processes
  - Pair production
  - Compton scattering
  - Photoionization

Number and energy of electrons (above 30 keV)

$E_{kin,0} = 100\,\mathrm{keV}$



$E_{kin,0} = 1\,\mathrm{MeV}$



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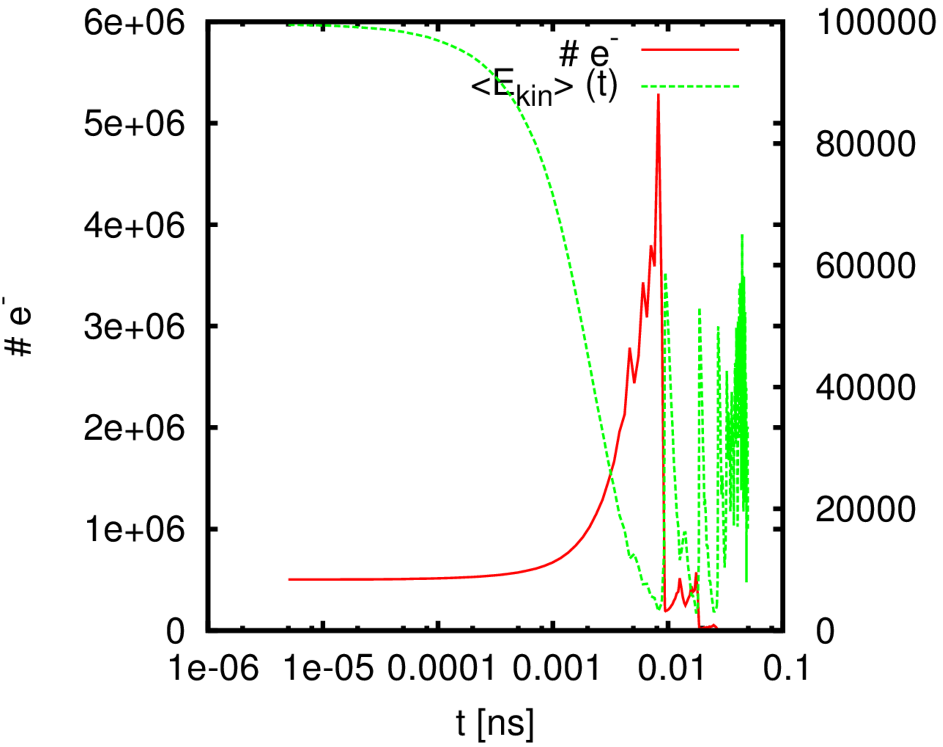

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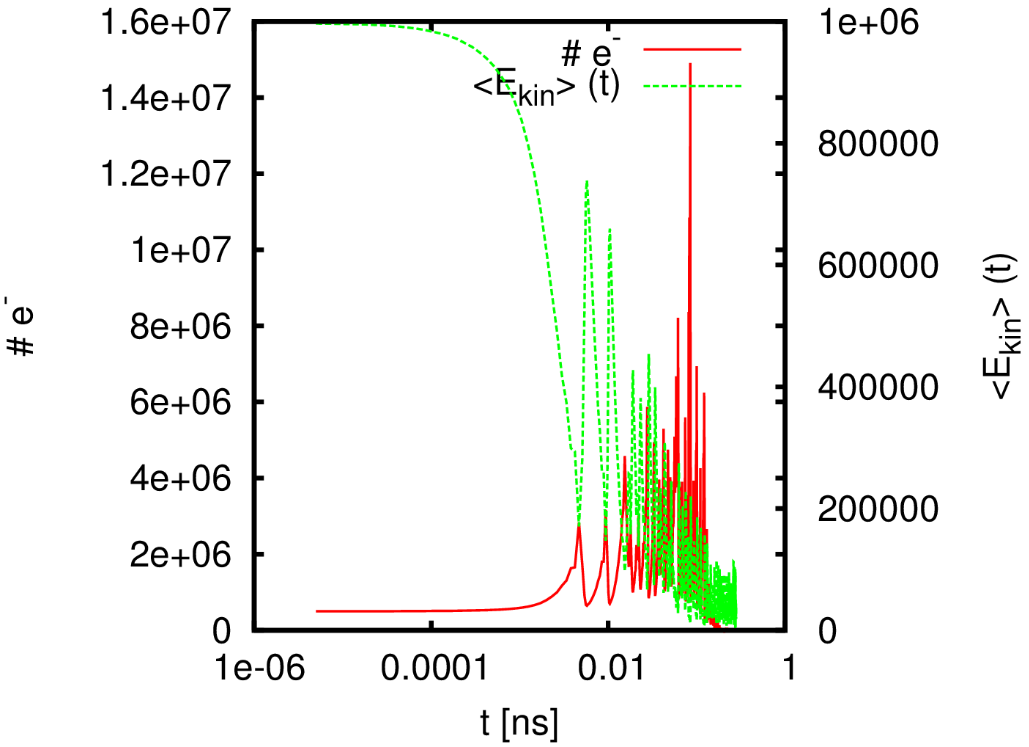

Increase of number of electrons due to ionization

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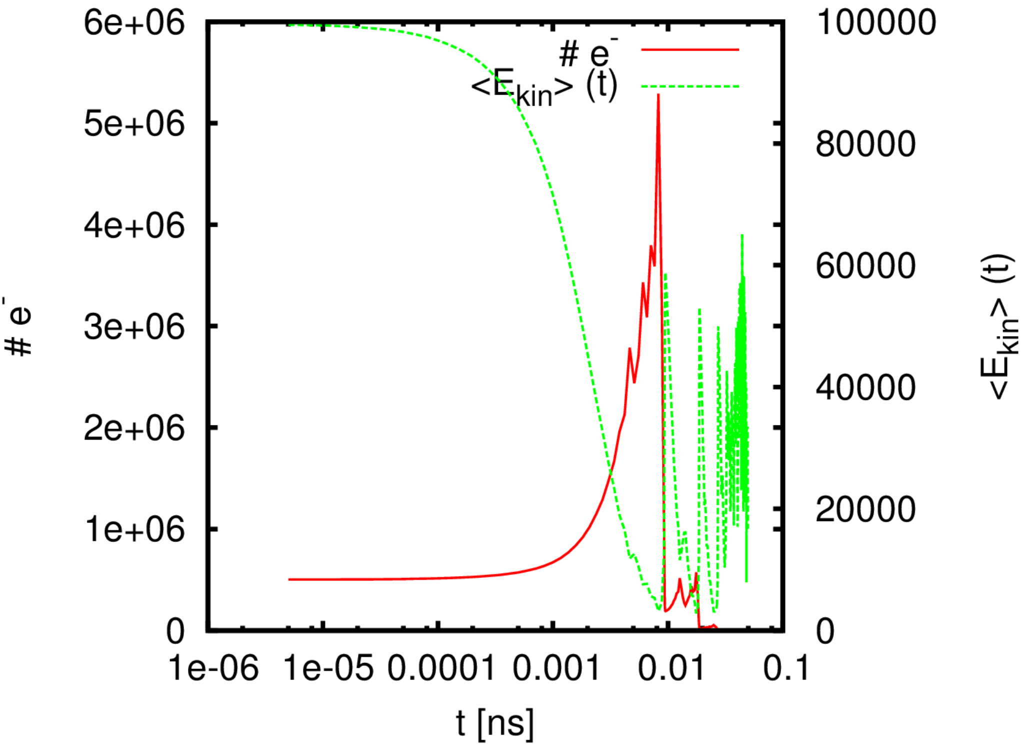
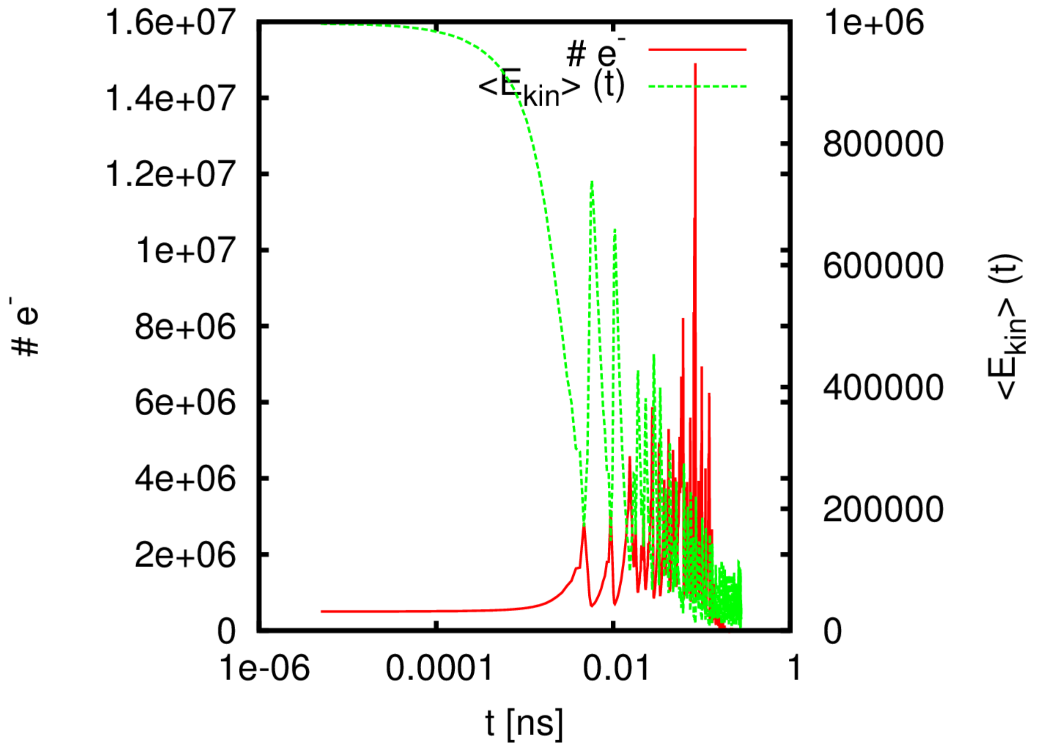


$E_{kin,0} = 1\,\mathrm{MeV}$

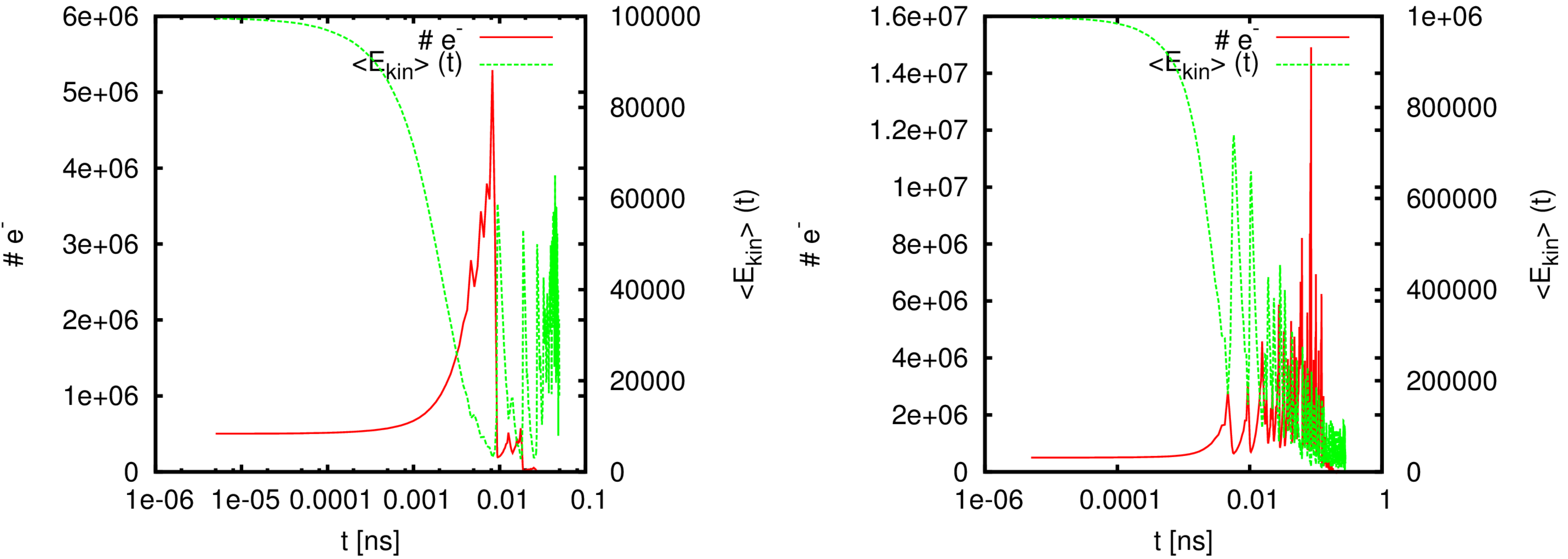


Increase of number of electrons due to ionization

Decrease of number of electrons due to removal of electrons with E <= 30 keV

Number and energy of electrons (above 30 keV)

$E_{kin,0} = 100\,\text{keV}$ $E_{kin,0} = 1\,\text{MeV}$



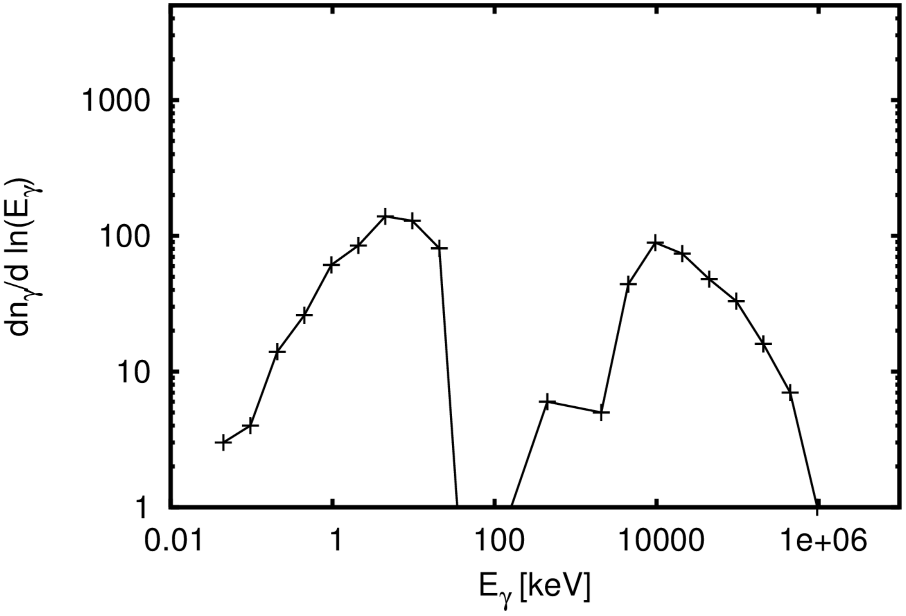
Increase of number of electrons due to ionization

Decrease of number of electrons due to removal of electrons with E <= 30 keV

Similar behaviour for mean energy

Energy of Bremsstrahlung photons

$$E_{kin,0} = 1\,\mathrm{MeV},\, n_e \equiv 0$$



Energy of Bremsstrahlung photons

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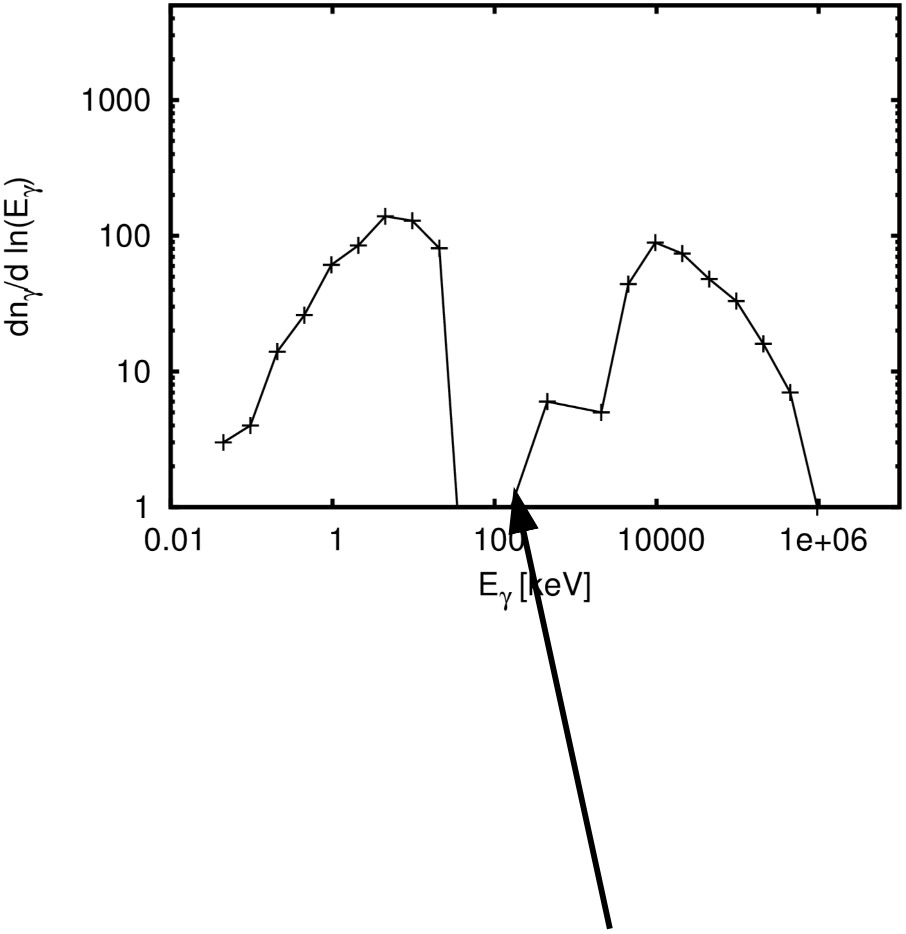

Gap due to photoionization

Energy of Bremsstrahlung photons

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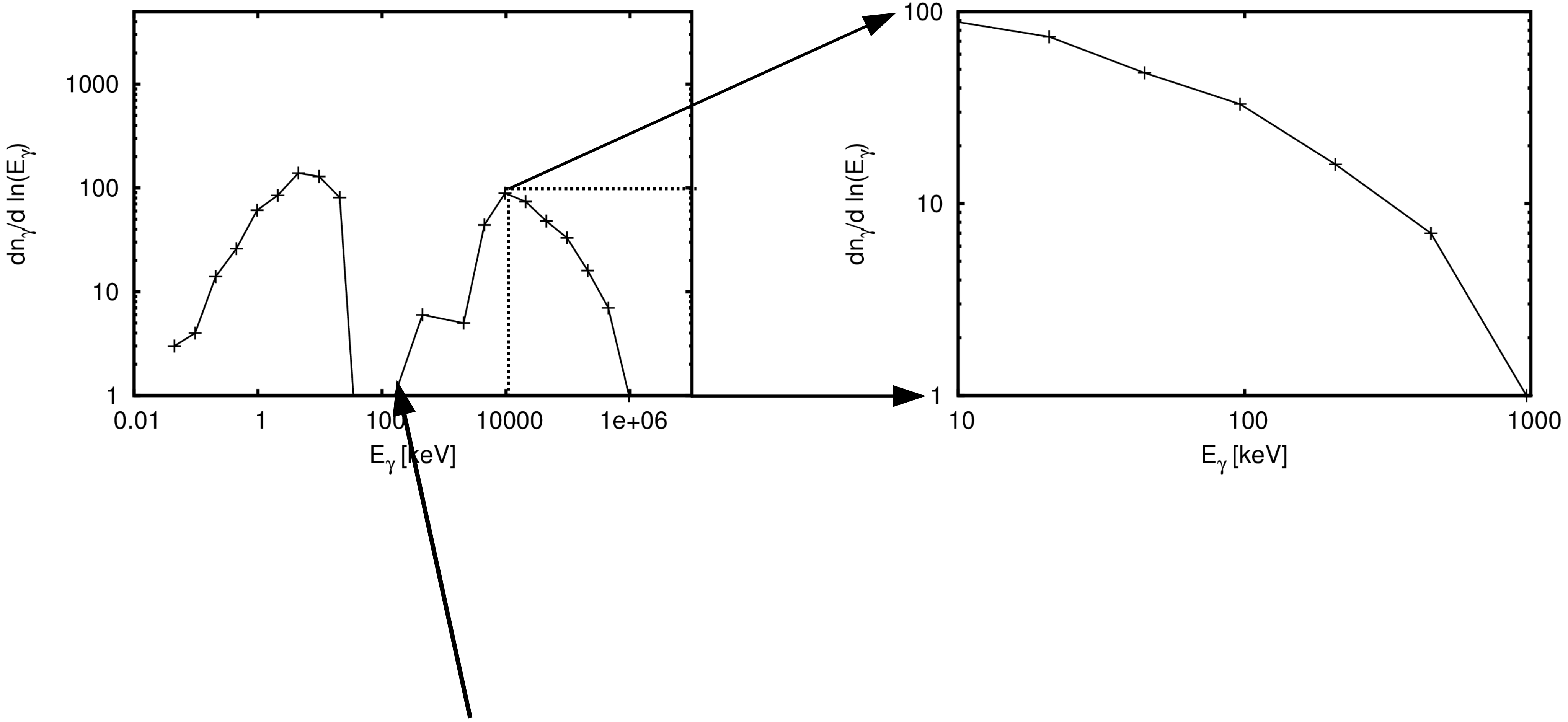
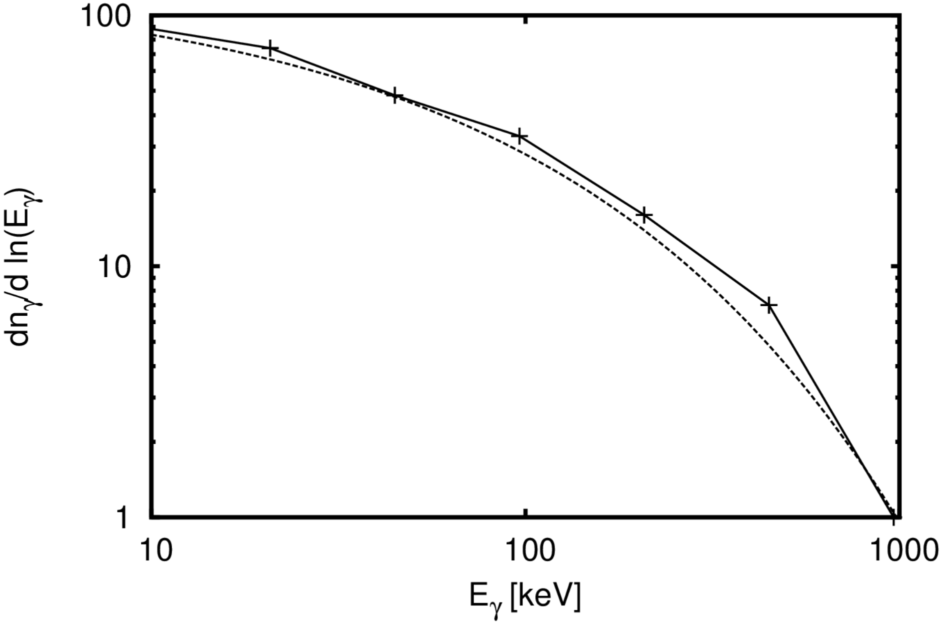


Gap due to photoionization

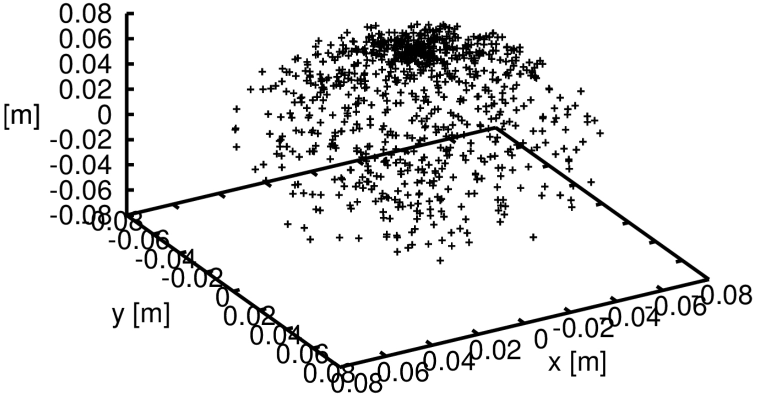
Fit function

$$n_\gamma(E_\gamma) = 142 \cdot e^{-0.0059 \cdot (E_\gamma[\mathrm{eV}])^{0.488}}$$

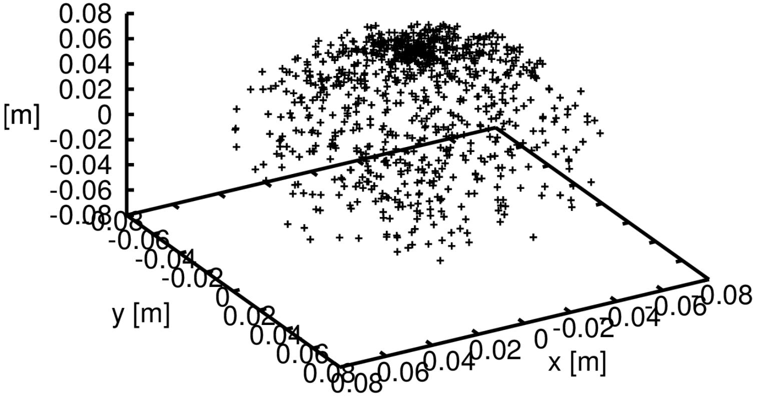
Decay of spectrum
(similar behaviour for
different electron energies)

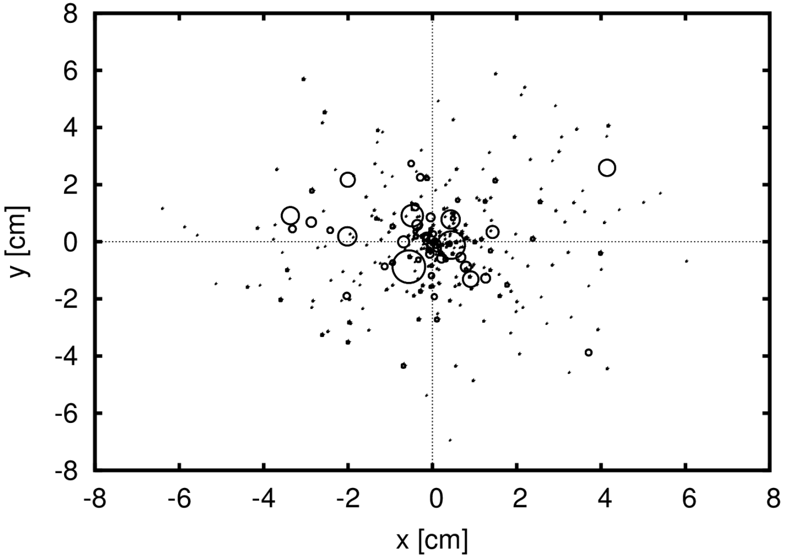


Spatial distribution of photons

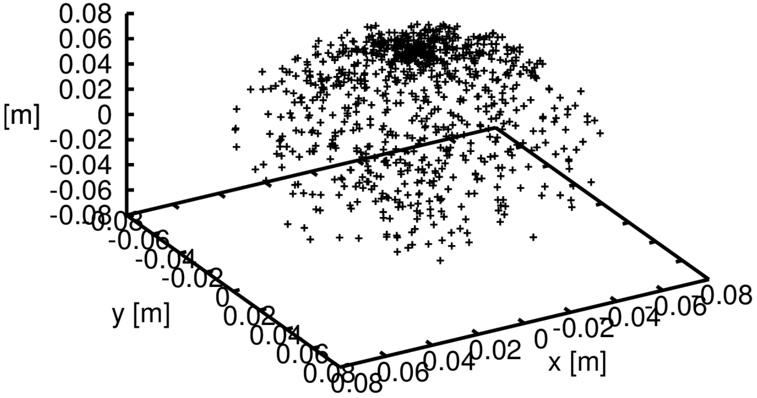


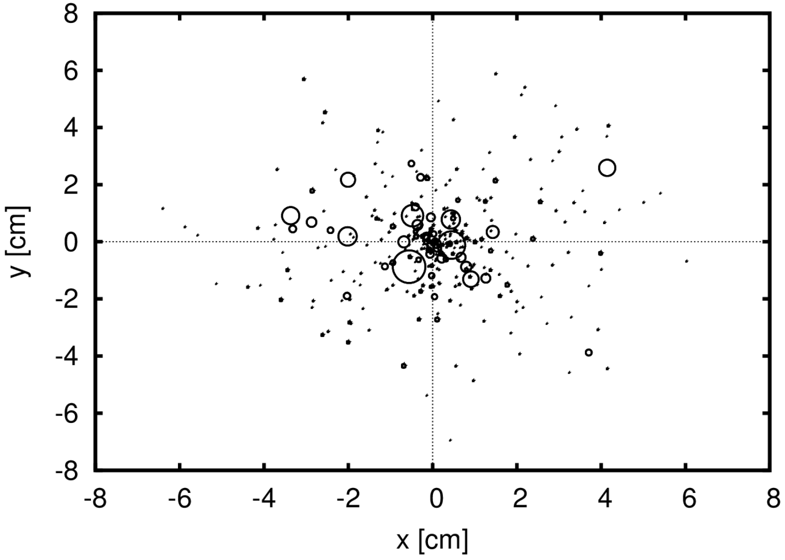
Spatial distribution of photons

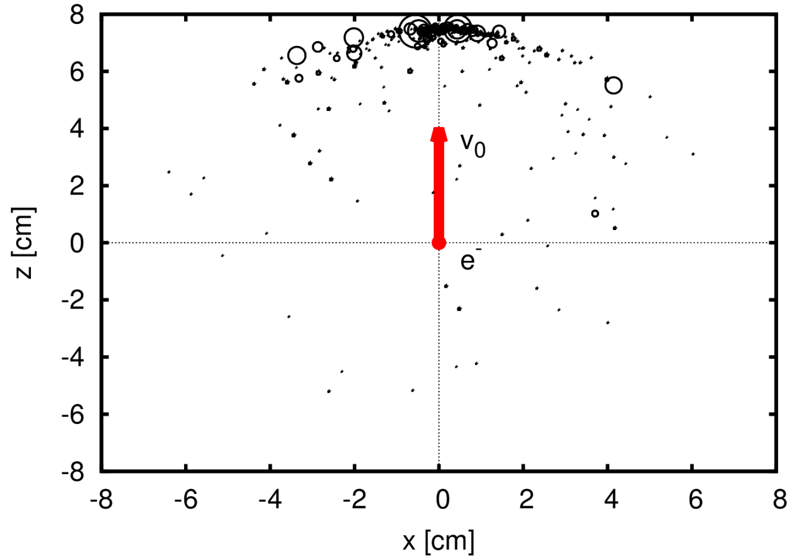


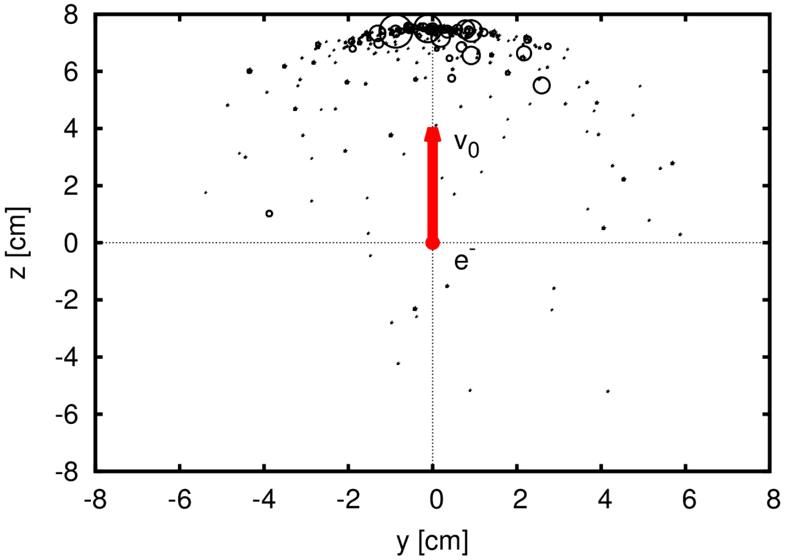


Spatial distribution of photons



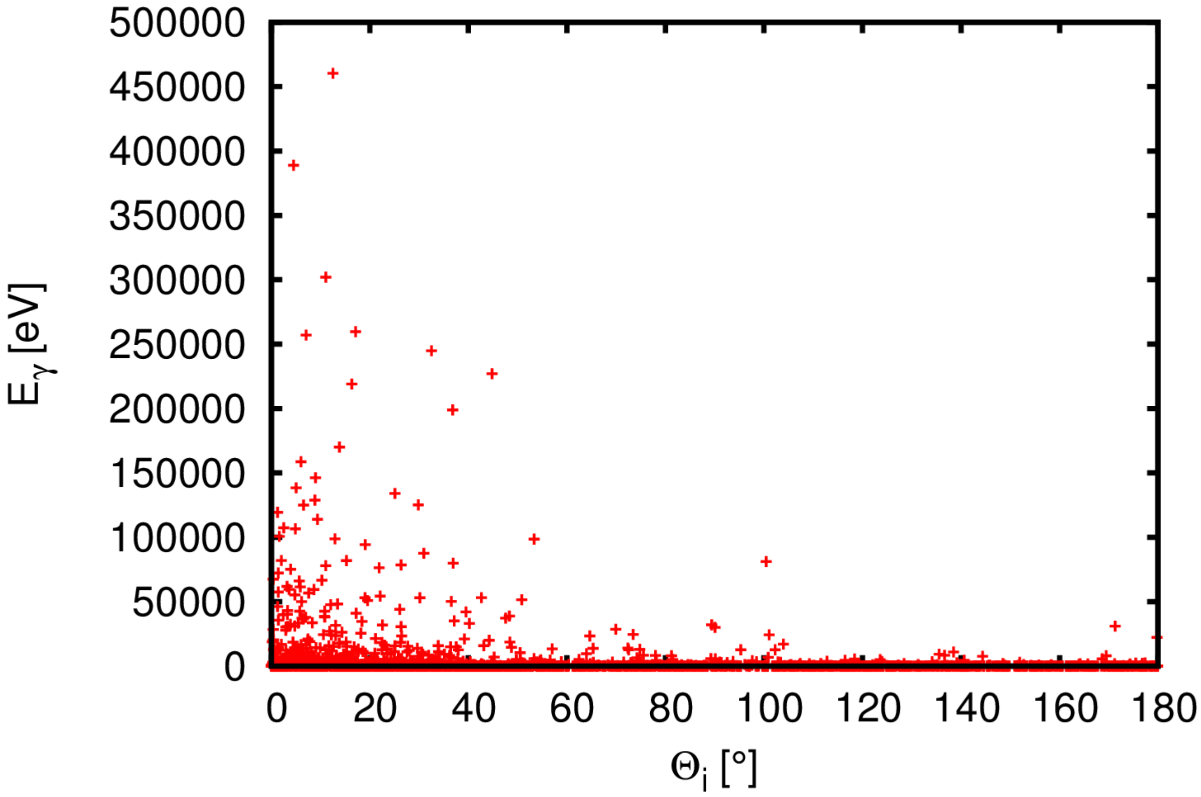






Direction of Bremsstrahlung photons

$E_{kin,0} = 1\,\mathrm{MeV}$

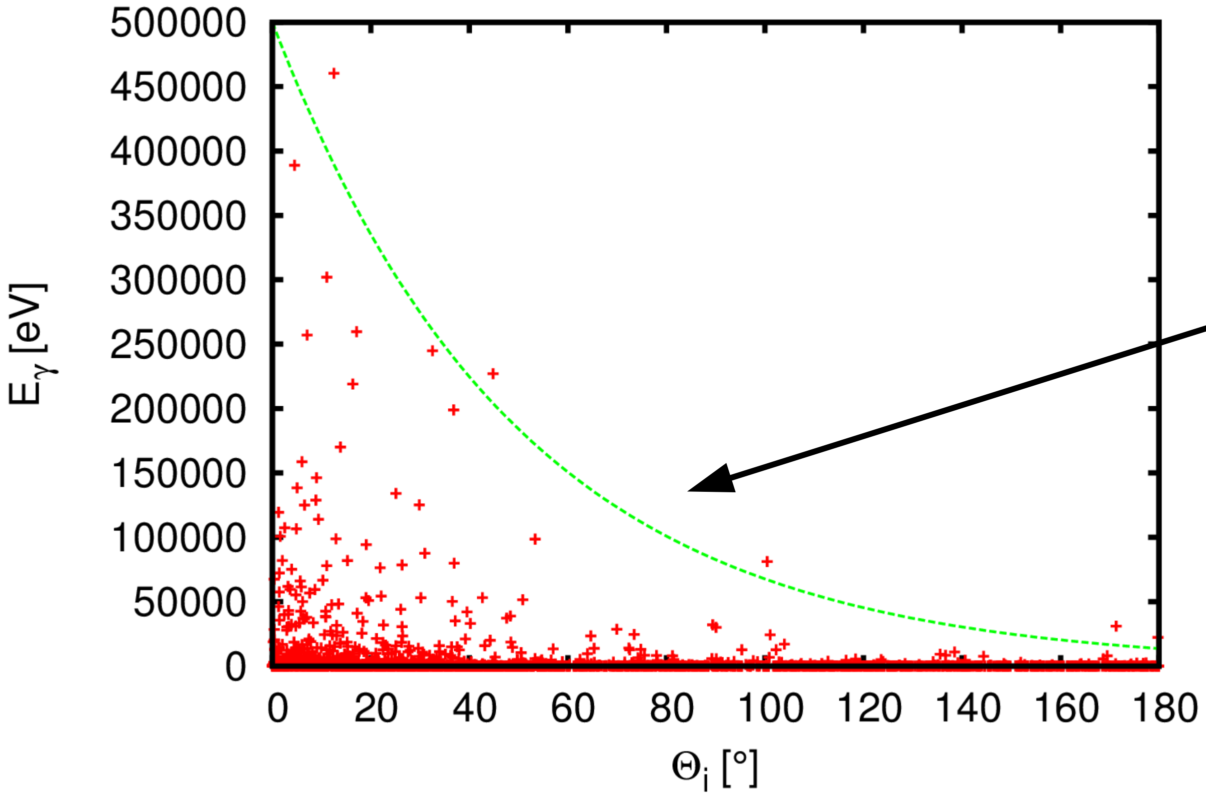


High energy photons emitted in forward direction

Scattering angle as a function of photon energy

Fit function

$$E_{kin,0} = 1\,\text{MeV}$$



Decreases as $e^{-0.045\,\Theta_i[^\circ]}$

(Similar behaviour for different electron energies)

Scattering angle as a function of photon energy

Use results as an input

- Energy spectrum of photons + fit

Use results as an input

- Energy spectrum of photons + fit
- Spatial distribution

Use results as an input

- Energy spectrum of photons + fit
- Spatial distribution
- Direction of photons + fit

Use results as an input

- Energy spectrum of photons + fit
- Spatial distribution
- Direction of photons + fit

- Also known (but not needed):
  - Number of electrons as a function of time
  - Energy of electrons as a function of time